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Scientific/Clinical Article

Tissue adaptation rate in the treatment of Dupuytren contracture

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ABSTRACT

Study Design: Basic research (cross-sectional).
Introduction: Dupuytren disease can cause disabling contractures of the finger joints. After partial fasciectomy, postoperative hand splinting helps to maintain extension range of motion.
Purpose of the Study: To measure how the contraction forces of the finger on the splint change over time.
Methods: Subjects who were treated for Dupuytren contracture with partial fasciectomy were invited to participate in this study. Force sensors were placed in their dorsal extension splint, and the applied force was measured continually for several weeks.
Results: Eleven subjects (aged 59-75 years) with the metacarpophalangeal (8) or proximal interphalangeal (3) as their most severely affected finger joint participated. Each night, the measured force consistently decreased to reach a plateau after about 3 hour (adaptation time, 2.55; 95% confidence interval, 0.2-31.8 hours). The time to reach this plateau decreased with time after surgery ($\approx$5%/day, $P = .0005$, $R^2 = 0.08$).
Discussion and Conclusions: The observed rate of decrease in the measured force indicates a tissue adaptation time of approximately 3 hours.

Introduction

Dupuytren is a genetic disease that affects the palmar aponeurosis, often resulting in contractures of the finger joints.[1] A contracture causes a deficit in range of motion (ROM) for a specific joint. This can make ordinary tasks such as a handshake or grasping a bottle of water very difficult, making it a real handicap for the patient.[2]

There are several accepted treatment methods for Dupuytren contracture, with collagenase injections[3] and needle fasciotomy[4] becoming popular. Many approaches of nonoperative treatment methods have been proposed and abandoned, and their application is still being experimented.[5] Often, partial fasciectomy is the choice of treatment, in which the affected tissue is surgically removed to loosen the contracture.[6] Postoperative physical exercises and wearing a hand splint at night may be prescribed to stimulate recovery and prevent new contractures.[7,8]

During the recovery process of the tissues in the hand, cross-links are formed to connect collagen fibers.[9] If these fibers are formed with the fingers flexed—the natural position of a relaxed hand—new contractures can form. The function of the hand splint is to help maintain the extension ROM during the recovery process and to help correct any residual contractures.[10] In this process, the longer the joint is held in its end range, the greater the gain is in ROM.[11]

Because the splint prevents flexion of the fingers, it applies an initial force on the fingers, stretching the tissues. At first, the tissues will resist, and the initial force (F_0) can be relatively high. However, over time, the tissues will adapt (amongst others due to viscoelastic stress-relaxation), and the process of wound recovery will change, both causing the force to decrease. Because the tissues adapt to their imposed new position, it can be assumed that the end range of the finger joint also shifts. Owing to this shift, after a certain amount of time, the finger joint will no longer be in its end range, and the force on the fingers reaches a plateau.

According to the total end range time principle (TERT), the longer a joint is held in its end range, the greater the gains are in ROM.[11] Several researchers have found that in the treatment of

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contractures, greater gains in ROM are achieved with longer splint use, both in hours and in weeks.[11-13] However, Jerosch-Herold et al,[14] Kemler et al,[15] and Collis et al[10] could not find evidence for the efficacy of postoperative night splinting in addition to hand therapy when compared with hand therapy alone. Some patients find the splint uncomfortable, and compliance is an issue.[15-17] In light of these recent findings, the function of postoperative splinting has become unclear, and postoperative splinting for the treatment of Dupuytren contractures has become a controversial topic.[17,18]

We investigated the process of tissue adaptation in the treatment of Dupuytren contractures on macrolevel by measuring the forces in a hand splint. Force is the main outcome measure in this study. One can imagine that a certain threshold force exists below which the body does not respond. For example, the gravitational force that acts on one's arms does not significantly elongate them. The force at the end of the relaxation period (the final force, F_∞) will reflect this threshold value. Mechanically speaking, the tissue behaves as a "spring-damper system." For such a system, the resisting force $F(t)$ depends on the adaptation rate (τ, in hours) and both the initial and threshold forced (F_0 and F_∞, in Newtons) as follows:

$$F(t) = (F_0 - F_\infty)\cdot e^{-\frac{t}{\tau}} + F_\infty \qquad (1)$$

The aim of present study is to characterize the adaptation rate of the tissue to give a new perspective on the discussion on the efficacy of postoperative splinting.

Methods

This is a descriptive study conducted at a single health center specialized in hand care (Handencentrum Enschede). The Medical Ethical Evaluation Committee of the Medisch Spectrum Twente reviewed the study according to the declaration of Helsinki and declared that it does not meet the criteria as stated by the Medical Research Involving Human Subjects Act (WMO) and therefore did not require their approval.

Participants

Patients of the Handencentrum Enschede who were treated for Dupuytren contracture with an open partial fasciectomy were asked to volunteer in this study. Our postoperative treatment protocol included application of a night splint. Only fingers with extension deficit contractures that were treated with a dorsal hand splint were included. Patients with infected or severely swollen wounds or with skin grafts were excluded. If patients were simultaneously treated for multiple fingers, the finger with the largest deficit was monitored. All patients provided written informed consent.

Study variables

Baseline information was collected including age, gender, affected digit (middle, ring, or little finger), affected joint (metacarpophalangeal [MCP], proximal interphalangeal [PIP], distal interphalangeal [DIP]), preoperative (pre-op) active range of motion (AROM), and treatment history. Postoperative (post-op) AROM and force of the hand on the splint were measured in the weeks after the surgery. Total active extension (defined as the sum of active MCP, PIP, and DIP joint extension) and total active flexion (defined as the sum of active MCP, PIP, and DIP joint flexion) were calculated.

Materials

A pocket finger goniometer (Exacta; North Coast Medical, Inc, Gilroy, CA) was used to measure AROM of the MCP and PIP joints in both extension and flexion. For the DIP joint, a Jamar goniometer was used (Preston, Jackson, MI). An accuracy of $\pm 5^\circ$ is mentioned for the measurement of finger joint angles.[19]

Force was measured using a custom-made force sensor (Fig. 1A), based on inductive sensing.[20] This sensor was specifically developed to overcome the difficulties with commercially available thin force sensors, such as drift, size, or costs. A digital DS1825 thermometer (Maxim Integrated, San Jose, CA) was included to allow correction for temperature drift. Extensive information about the force sensor and its performance is available in a separate article.[21] The specifics are summarized in Table 1.

Measurement protocol

Three to five days after the surgery, a custom-made hand splint was fitted to the patient. Before placement, the force sensors were carefully calibrated using ten weights of 100 g each. Then, the force sensor and thermometer were placed on the inside of the splint, underneath the customary layer of foam, to prevent any direct contact with the skin. Depending on the most affected joint (MCP or PIP), the force sensor was located at the distal part of the metacarpal or the proximal phalanx (Fig. 1). The data logger was attached on the outside of the splint with Velcro.

After standard treatment, the patient was instructed to use the splint at night only and return weekly to have the therapist assess the finger and adjust the splint if necessary. In certain cases, additional daytime use of 3×1 hour per day was advised.

At every weekly visit, the battery and memory card were replaced, and the AROM of the affected finger was measured. After 3 weeks, the force sensor was removed from the splint. Night-time splint use continued for several months, and a short-term follow-up AROM measurement was planned 3 months after the surgery.

Data analysis

Each retrieved data set consisted of time, force, and temperature data of 1 week. Donning and doffing resulted in a sudden change in temperature, and corresponding times were manually identified in the postprocessing stage. Each identified selection was defined as a wear period.

Wear periods

For every wear period, the duration and time since surgery were determined. Each wear period's force data were fitted to Equation 1 using MATLAB 2016b's fit function. This function generates values and 95% confidence intervals (CIs) for F_0, τ and F_∞. The used restrictions (bounds) for this fit function were $0.001 < \tau < 2000$ hours and $F_\infty < F_0$. The adaptation time was defined as 3τ, which represents the required time to reach 95% of the equilibrium.

Wear periods were excluded for further analysis if the duration was shorter than half an hour, the goodness of fit (R^2) was less than 0.01, or the 95% CI for τ included negative numbers.

Statistical analysis

The distribution of extracted data values was checked for normality using Lilliefors tests. Finger AROM differences between pre-op, post-op, and follow-up were tested for significance using Mann-Whitney *U*-tests. Statistical significance was defined as $P < .05$.

The influence of the time since surgery on variations in duration, adaptation rate (τ), initial force (F_0), and final force (F_∞) were analyzed with a linear regression. For this regression, the logarithm of the adaptation rate was used because it had a log-normal distribution. The result of that regression was transformed with

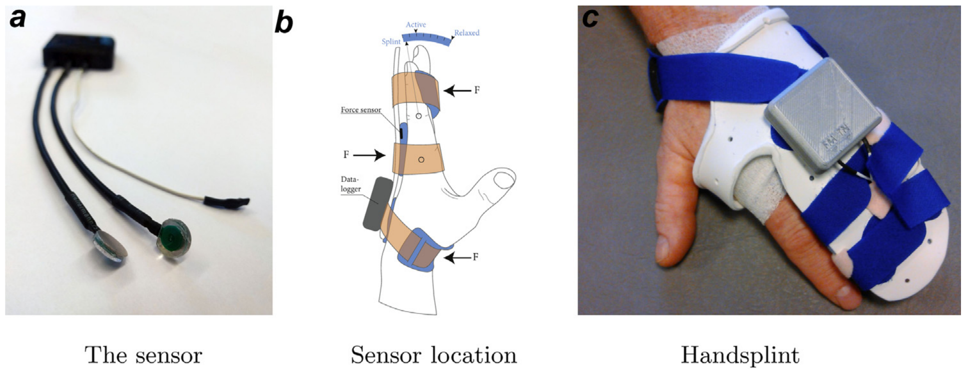

Fig. 1. Use of the force sensor. (**A**) A custom-made inductive force sensor (**B**) was placed on the hand splint to measure the force of the hand on the splint. (**C**) Wires were routed distally, and the data logger was attached to the dorsal side of the splint with Velcro.

$$\begin{aligned}\log(\tau) &= A + B\cdot t,\\ \tau &= e^{(A+B\cdot t)},\\ \tau &= e^{A}\cdot e^{B\cdot t}, \text{ and}\\ \tau &= C\cdot\left(e^{B}\right)^{t},\end{aligned}$$

in which A and B and the resulting coefficients form the linear regression, C is the initial adaptation rate, and e^B is the decay rate.

Results

Subject characteristics

After signing informed consent, initially, 17 subjects were enrolled, of which 6 were excluded due to severely swollen wounds or a suspected infection. A total of 11 subjects were included in the study. Subject characteristics are summarized in Table 2.

Active range of motion

The surgery promptly improved AROM of the MCP joint for extension ($P = .006$) and remained improved in follow-up as shown in Table 3 and Figure 2. Flexion AROM decreased after surgery but improved in the weeks after the surgery.

Splint forces

With the exception of one subject in which the sensor failed after 2 days, the force of the affected finger on the splint was measured for several weeks (range, 10-24 days). A typical measurement is shown in Figure 3. Of the 210 identified wear periods, 153 met the criteria stated in 2.5.1 and were included for further analysis. The extracted data from these wear periods are presented in Table 4. The force decreased over time with a mean adaptation rate of 0.85 hours; hence, the adaptation time was 2.6 hours.

Influence of time since operation

With every day, the adaptation time decreased somewhat ($\approx 5\%$/d, $P = .0005$, $R^2 = 0.08$) (Fig. 4). Similar trends were found for duration (-5 min/d, $P = .03$, $R^2 = 0.03$), initial force (-0.01 N/d, $P = .003$, $R^2 = 0.06$), and final force (-0.007 N/d, $P = .04$, $R^2 = 0.03$).

Discussion

The extension deficit caused by the effects of Dupuytren was successfully treated in all subjects. Although MCP extension had significantly improved after the surgery, flexion AROM temporarily worsened, most probably due to swelling and sensitivity of the wound. The follow-up AROM measurements showed that after 3 months, the improvement of finger extension was effectively maintained and that finger flexion was regained. However, Dupuytren's contracture is known to be recursive, and follow-up was too short to make any statements about long-term results.

Total end range time

The TERT theory is based on a study looking at posttraumatic PIP joint stiffness. In their experiment, Flowers and LaStayo[11] used plaster casts, which can be considered an even more static approach than using a hand splint. Still, they found that removing

Table 1
Force sensor characteristics

Characteristics	Value
Dimensions (ø × thickness)	10 × 2.3 mm
Resolution	0.15×10^{-3} N
Accuracy	≈3.4%
Sample rate	18 Hz
Drift	$<2.1\%/\log_{10}$ (hr)
Hysteresis	≈6.0%
Temperature drift	≈−0.1 N/°C

More detailed information about the custom-made inductive force sensor is published here.[21]
A data logger equipped with a small battery and micro-SD card was used to locally store the measurements of both the force sensor and the thermometer (Fig. 1A). The system was programmed to store data continually for periods of 10 seconds, 6 times per hour, and can operate for at least 7 days without requiring any interventions.

Table 2
Subject characteristics

Variable	Results
Age, mean (range)	67 (59-75) y old
Gender (M/F)	6/5
Treatment history (yes/no)	5/6
Hand (L/R)	6/5
Finger (middle/ring/little)	0/5/6
Joint (MCP/PIP/DIP)	8/3/0

M = male; F = female; L = left; R = right; MCP = metacarpophalangeal; PIP = proximal interphalangeal; DIP = distal interphalangeal.
This table presents the specifics for the selected fingers only. In the case of multiple affected fingers and joints, the most severe one was selected. Treatment history is any previous surgery related to the Dupuytren disease.

Table 3
Active range of motions (AROM) in the finger joints

Joint		Pre-op	Post-op	Follow-up	Pre vs post	Pre vs follow	Post vs follow
	n	9	10	6	*P*	*P*	*P*
MCP	Extension	32 (−10 to 58)	1 (−7 to 22)	3 (−3 to 18)	**.006**	**.023**	.624
	Flexion	85 (68 to 92)	41 (16 to 66)	85 (75 to 89)	**.000**	.670	**.000**
PIP	Extension	10 (1 to 61)	8 (2 to 43)	5 (0 to 28)	.734	.368	.471
	Flexion	92 (80 to 101)	66 (26 to 94)	85 (80 to 104)	**.002**	.711	**.016**
DIP	Extension	−7 (−21 to 0)	−10 (−24 to 12)	−11 (−21 to −5)	.796	.212	.474
	Flexion	51 (39 to 69)	31 (6 to 50)	59 (36 to 71)	**.001**	.508	**.005**
TAE		30 (14 to 95)	−2 (−16 to 77)	3 (−14 to 13)	**.002**	**.000**	.654
TAF		224 (214 to 241)	135 (48 to 194)	228 (204 to 258)	**.000**	.796	**.000**

MCP = metacarpophalangeal; PIP = proximal interphalangeal; DIP = distal interphalangeal; TAE = total active extension; TAF = total active flexion.
Data are presented as median (range) in degrees. Statistically significant AROM differences between pre-op, post-op, and follow-up are presented in bold.

the cast after 6 days resulted in a significantly greater ROM than did removal after 3 days. Following their theory that ROM only improves when a joint is held in its end range and assuming that a certain threshold force is needed to keep a joint in its end range, it can be concluded that a certain threshold force is needed to improve ROM. Our interpretation of Flowers and LaStayo's[11] measurements is that after 3 days, the force must still be above the threshold force. Our measurements consistently show that a plateau is reached within hours. Be aware that Flower's subjects had closed trauma, whereas ours had open fasciectomy.

Postoperative orthotic application

Without proper postoperative care, the surgically gained ROM might soon be lost again due to wound contraction and scar tissue formation in a relaxed (ie, flexed) position. Hand therapy prevents stiffening of the joints and stimulates recovery. The hand splint may help to maintain the ROM that is gained with the surgery.

A hand splint is intended to hold the affected joint in its end range, similar to the plaster cast did in the experiment of Flowers and LaStayo.[11] Our results consistently show that with this static approach, the force decreases over time to reach a mechanical equilibrium within hours. On average, the adaptation rate was calculated to be 0.85 hours, so in most cases, 95% of the equilibrium (the adaptation time, 3τ) was reached after wearing the splint for about 3 hours. When the force has reached the equilibrium, the joint can no longer be in its end range, and as the joint is immobilized by the splint, the end range must have shifted. Following the TERT principle, the splint would only improve ROM during the few

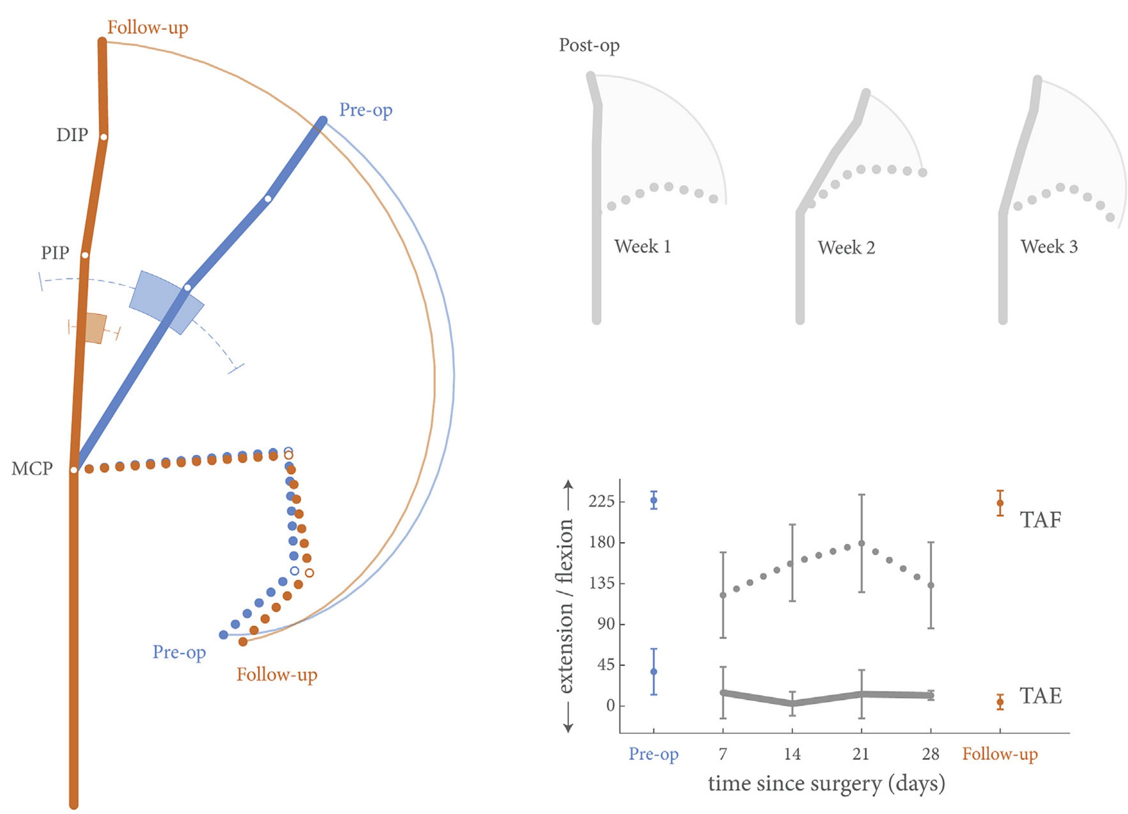

Fig. 2. AROM change. (*Left and top*) Average AROM measurements of all subjects combined. Before surgery (*blue*), a substantial extension deficit in the MCP joint could be observed. After surgery (*gray*), this deficit was almost completely removed, although finger flexion was hindered. In follow-up, after 3 months (*orange*), the range of motion of the finger was improved both in extension and in flexion. (*Bottom right*) Post-op AROM measurements of all subjects combined, grouped per week after the surgery. AROM = active range of motions; MCP = metacarpophalangeal; PIP = proximal interphalangeal; DIP = distal interphalangeal; TAE = total active extension; TAF = total active flexion.

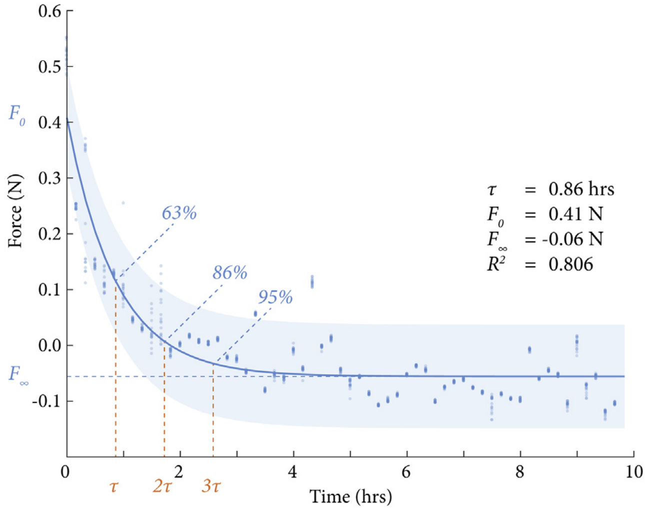

Fig. 3. One wear period. A typical example of the force measurement of one wear period. Six times per hour, the force is logged for 10 seconds, represented by the vertically grouped blue dots. The prediction from the fit is presented as a solid blue line. The light blue area represents the 95% confidence interval of the fit. After $t = \tau$, $t = 2\tau$, and $t = 3\tau$, the force has decreased by 63%, 86%, and 95%, respectively.

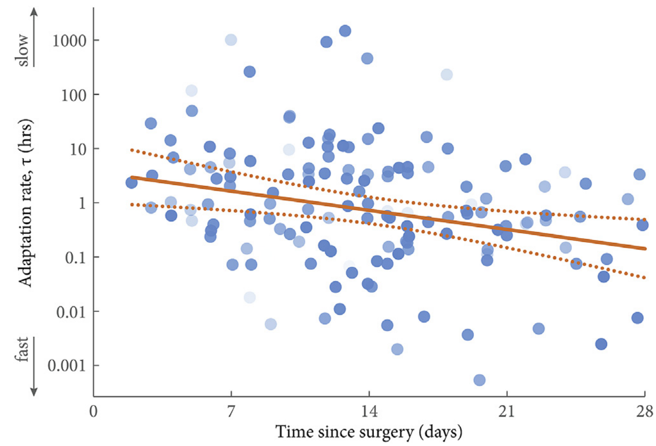

Fig. 4. Adaptation rate vs days. After the surgery, the adaptation time decreased somewhat. Every *blue dot* represents the calculated adaptation rate of one wear period, and its opacity represents the goodness of fit (R^2) for that wear period. The solid orange line represents the fit to the data ($\approx$5%/d, $P = .0005$, $R^2 = 0.08$), with the *dotted orange* line representing the 95% confidence interval to this fit.

hours before reaching the mechanical equilibrium. However, other factors that were not measured, such as compression, might have an effect on the adaptation of the tissues. More research is needed to assess the minimal wear duration.

Wound contraction

During the proliferation phase of wound recovery, myofibroblasts surrounding the wound produce collagen and contract to close the wound.[9] Wound contraction is usually most prominent in the first weeks after the surgery, and the greatest risk of losing ROM can be expected. This phenomenon is reflected in our observation that the adaptation time decreases in the weeks after the surgery. It suggests that in the first days or weeks after the surgery, the tissue is more plastic; therefore, more ROM can be regained, and it takes longer to reach the equilibrium. In later weeks, the wound matures and less ROM is lost, hence the decreasing adaptation time. Following this principle, the splint should be used at least as long as the wound recovery continues. Indeed, hand therapists prescribe splint use for 3 to 6 months.[10]

Study limitations

Because the force sensors were not placed directly on the skin but rather underneath a protective layer of foam, the measured forces did not equal the actual forces on the finger. This does not influence the magnitude of τ but could give unrealistic low values for F_∞ and F_0 because the force is distributed over a larger area than measured.

The exclusion of a wear period for further analysis based on its force data might create a risk of confirmation bias. However, the force data of these excluded wear periods would appear to have multiple spikes or an overall chaotic pattern, resulting in a low goodness of fit and a large 95% CI for τ when trying to fit the data into Equation 1. This profile fits the description of subjects mentioning that occasionally they would readjust or remove the brace at night. In those cases, the exact beginning and end of a wear period could not be determined in the postprocessing period because these actions would not result in a sudden temperature change. Therefore, exclusion based on the fit analysis is justified.

For safety and comfort, a relatively small battery was used, which required the use of an intermittent measurement protocol to save battery power. The force and temperature were measured every 10 minutes, which means that the exact beginning of each wear period has a maximum error of 10 minutes. This error will have influenced the accuracy of the calculation of small adaptation rates (<0.5 hours). The error will also have influenced the magnitude of F_0 but not of F_∞.

From a scientific point of view, passive ROM might have been a more relevant measure than active ROM, but for ethical reasons, we were unable to deviate from the standard treatment protocol.

The choice to only include the finger with the largest deficit in case of multiple affected fingers might have skewed the outcomes.

Although a clear decrease in force was observed, it does not necessarily say anything about the internal structures in the hand. No medical imaging techniques were used to be able to correlate the measured force to physical changes in the hand. The reached mechanical equilibrium within several hours suggests rapid tissue adaptation but does not provide hard evidence because the correction of contractures might be multifactorial.

Table 4
Wear periods

Measure	Results	
N	153	
Duration	7.3	IQR: 3.7-9.0 hrs
Adaptation rate (τ)	0.85	95% CI: 0.1-10.6 hrs
Adaptation time (3τ)	2.55	95% CI: 0.2-31.8 hrs
Initial force (F_0)	0.07	IQR: 0.01-0.29 N
Final force (F_∞)	−0.08	IQR: −0.31 to 0.01 N

The values for adaptation rate are log-normally distributed (Lilliefors, $P = .09$), so the transformed mean and 95% confidence interval (CI) are given. The values for duration, F_0 and F_∞, are not normally distributed ($P = .002$, $P = .001$, and $P = .001$, respectively), so the median and interquartile ranges (IQR) are given.

Conclusions

Forces in postoperative splinting in the treatment of Dupuytren contracture were measured. Each night, the observed force decreased to reach the equilibrium after about 3 hours. In the weeks after the surgery, the adaptation time decreased slightly, so every week, the equilibrium was reached earlier.

Acknowledgments

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#1. The study design was
   a. RCTs
   b. retrospective cohort
   c. cross-sectional
   d. systematic review

#2. All subjects
   a. underwent partial fasciectomy and wore a dorsal extension splint
   b. underwent partial fasciectomy and wore a palmar extension splint
   c. were treated with a static-progressive dorsal extension splint
   d. were treated by injection and manipulation

#3. How many subjects participated in the study
   a. 8
   b. 9
   c. 10
   d. 11

#4. The following was done
   a. manipulation was performed TIW
   b. a Marcaine drip was offered to the patient for the first 48 hours post op
   c. a force sensor was incorporated into the splint
   d. deep friction massage to the wound after 10 days

#5. The average time needed to achieve tissue adaptation was approximately 3 hours
   a. not true
   b. true

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